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ACIDIC PRECIPITATION IN ONTARIO STUDY

METEOROLOGICAL STUDIES TO QUANTIFY THE EFFECTS OF SUDBURY EMISSIONS ON PRECIPITATION QUALITY AND AIR QUALITY DURING 1980-1983 WITH EMPHASIS ON THE SHUT-DOWN PERIOD

ARB-192-84-AQM

APIOS-017-84

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Synopsis

Meteorological studies to quantify the effects of Sudbury emissions on precipitation and air quality during the period 1980-1983 indicate that mean sulphur concentrations in precipitation were depressed at central, eastern and southeastern Ontario during the Sudbury emission shut-down period (July 1982 - March 1983) with trajectories from the Sudbury sector. Nitrate concentrations were also depressed. Mean SO_2 and sulphate air concentrations were significantly lower at northern, central, eastern and southeastern Ontario during the shut-down period relative to values for the analogous period from the previous year for Sudbury sector trajectories. Preliminary estimates of SO_2 dry deposition contribution from Sudbury sources range from 18% at Kapuskasing to about 3% at Longwoods. For sulphates, the approximate dry deposition contributions are 7% to Kapuskasing and about 4% to Charleston Lake. The area of potential dry deposition impacts extends from Sudbury in every direction with a slight preference for the region to the east.

SUDBURY SHUTDOWN STUDY - METEOROLOGY

INTRODUCTION:

This report describes attempts to use meteorology, and specifically air trajectories, to quantify the effect of the Sudbury emissions on precipitation quality and air quality in Ontario with particular emphasis on the nine months Sudbury shut-down period (July 1982 - March 1983). In this study, three periods have been selected for analysis, the Sudbury smelter shut-down period and two analogous periods from the previous years, namely, July 1980 - March 1981 and July 1981 - March 1982. The report is divided into sections each of which addresses a particular question. These questions are:

1. How did the quality of precipitation borne by air coming from Sudbury differ during the Sudbury shut-down period from the two analogous periods in previous years? - Section I.

2. What kind of variations in long term wet deposition patterns over the 3 periods would the meteorological variations appear to imply? - Section II.

3. How does the air quality itself reflect air mass origin and Sudbury influence? - Section III.

4. What is the relative impact of the Sudbury plume on surrounding regions? - Section IV.

I. Mean Sulphate loading and concentrations from the Sudbury sector.

Method

The appropriate sector and trajectory length were chosen, relative to Sudbury, for each of 6 event sites (Dorset, Longwoods, Railton, Fernberg, Chalk River[1] and Kapuskasing[2]), see Figure 1, and the mean loading per event and the mean concentration per event for that sector and that trajectory length were computed. The Sudbury sector is defined as the 'octant of origin' from the event site which includes the Sudbury area, and the trajectory length is based on travel time of air parcels from the Sudbury area to the individual event site (see Figure 2). For example, air parcels from Sudbury take about 6 hours, on average, to reach Dorset in a northwesterly flow. Thus, loading and concentration statistics are based on 6 hour northwesterly trajectories. Similarly, Longwoods statistics are based on 12 hour northerly trajectories, Railton statistics are based on 12 hour northwesterly trajectories, Fernberg statistics are based on 24 hour easterly trajectories, Chalk River statistics are based on 6 hour west northwest trajectories and Kapuskasing (N) statistics are based on 12 h south-southeast trajectories.

Results

Mean sulphate loadings did not appear to be depressed during the shut-down period at any of the sites (Table 1A). Loadings, in fact, varied in general with precipitation amount as a comparison of Tables 1A and 1C demonstrates. Mean sulphate concentrations, on the other hand, were typically lower at central, eastern and southeastern Ontario during the shut-down period.

Mean nitrate concentrations (Table 1B) in general were also low at central, eastern and southeastern Ontario during the shut-down period relative to values for the previous 2 years. The concentration reduction of nitrates cannot be attributed to the shut-down of the Sudbury sources, since the smelters are not significant emitters of nitrogen oxides.

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1 site data supplied by Environment Canada

2 site data supplied by Ontario Hydro

The sulphate and nitrate concentration data in precipitation for the Dorset, Longwoods, Railton and Fernberg sites were also normalized by computing the ratios of the mean pollutant concentration in the sector containing the Ohio Valley emissions to that in the sector containing Sudbury emisions and were based on 24 hour backward trajectories for the sector analysis. As Table 2A indicates, the central and southern Ontario locations had higher ratios for the shut-down period than for the analogous periods of the 2 previous years. This appears to be evidence of a discernible effect due to the Sudbury shut-down. It is to be noted, however, that the nitrate ratios are also higher for the shut-down period (Table 2B).

II Synoptic Class Distribution for Precipitation Events at 4 locations during Shutdown and for analogous periods in the 2 previous years

Method

For the shut-down period and for similar periods in each of the 2 previous years, the synoptic class according to the synoptic typing system of Heidorn (see Appendix 1) was determined. Tables 3-6 indicate the percentage of events and the percentage of precipitation amount corresponding to each synoptic class for each of the 3 periods for the Dorset, Longwoods, Railton and Fernberg sites.

Results

The following conclusions emerge from this analysis:

1. For all the locations and each of the 3 periods, Synoptic Classes 3,5 and 1 were most frequently associated with precipitation. These are, respectively: pre-warm front, cyclonic, and post-cold front situations. The first two are associated with generally southerly winds (see Maps in Appendix) and the last is associated with north or north-westerly winds behind the winter cold front.

2. With one exception, most of the precipitation was associated with Classes 3 and 5. The one exception was Longwoods for 1980/81 when Class 6 also appeared significant.

Implications for Expected Cumulative Wet Deposition Patterns.

Since only 3 "seasons" of data were available, our ability to define normal synoptic class statistics is severely limited. However, some subjective statements regarding the expected deposition variations resulting solely from synoptic meteorological considerations may be gleaned from Tables 3-6.

1. The relative effect on precipitation quality in south and central Ontario due to long range transport from the heavily industrialized North Central U.S. emissions region was probably higher in the shut-down period than it was in the previous analogous periods. This difference is reflected in the higher percentage of both events and total rainfall (gauge depth) associated with Synoptic Class 3 for the period 7/82 - 3/83 (Tables 3-5).

2. The relative effect on precipitation quality due to long range transport of emissions from the Atlantic States into south and central Ontario was considerably higher in the period 7/81 - 3/82 than in the analogous period in the year before, or in the shut-down period in the year following, particularly in Eastern Ontario (Table 5).

3. The overall quality of precipitation in south and central Ontario might be expected to be best (i.e. lowest in sulphate and nitrate) in 1980/81 due to a lower frequency of Synoptic Class occurrences associated with south and southwesterly flows.

III. Air Concentrations and Depositions from the Sudbury Sector

Method

The methodology used for this analysis is similar to that described in Section I. Accordingly, for Dorset, the air concentration statistics are

based on 6 hour northwesterly trajectories for the Sudbury sector. Similarly, Longwoods statistics are based on 12 hour northerly trajectories, Charleston Lake statistics are based on 12 hour northwesterly trajectories, Fernberg statistics are based on 24 hour easterly trajectories, Chalk River statistics are based on 6 hour west-northwest trajectories and Kapuskasing statistics are based on south-southeast trajectories. The data analyzed consisted of sulphur dioxide, sulphate, nitrate, nitric acid and ammonia, and the results are displayed in Tables 7 and 8.

Results

The following conclusions emerge from this Sudbury sector analysis:

1. With trajectories from the Sudbury sector, mean sulphur dioxide and sulphate air concentrations were depressed during the shut-down period (7/82-3/83) at Dorset relative to values for the two analogous periods from the previous years (7/80 - 3/81 and 7/81 - 3/82) (see Tables 7A and 7B). For example, mean SO_2 concentrations for the period 7/81 - 3/82 were 8.66 ug/m^3 and for the shut-down periods were 1.28 ug/m^3. For sulphate, mean concentrations for the period prior to the shut-down were 1.42 and 2.28 ug/m^3 and only 0.70 ug/m^3 for the shut-down period. These results are statistically significant at the 5% probability level based on median 2-sample tests. For the other pollutants, i.e. nitrate, nitric acid and ammonia, the variations in concentrations for the three periods at Dorset were not statistically significant.

2. Mean sulphur dioxide air concentrations were also depressed during the shut-down period at Charleston Lake, Longwoods, Chalk River and Kapuskasing with the trajectories from the Sudbury sector relative to values for the analogous period from the previous year (Table 8A). A decrease in mean sulphate concentration during the shut-down period was also noted at Charleston Lake, Chalk River and Kapuskasing. On the other hand, an apparent increase effect on sulphate levels was noted at Longwoods. Based on limited data, the Fernberg site shows no apparent impact from the Sudbury sector.

3. Since dry deposition can be related to air concentration, Table 7 was used to provide some preliminary estimates of the relative contribution of Sudbury sources. SO_2 dry deposition contribution from Sudbury sources was estimated to be approximately 11% at Dorset. For sulphates, the dry deposition contribution is estimated to be approximately 4% at Dorset. Using this approach, the dry deposition contributions of SO_2 and sulphates at Charleston Lake from Sudbury sources were estimated to be 7% and 4% respectively. At Longwoods, the dry deposition contribution of SO_2 from Sudbury sources was about 3%. For Chalk River, the dry deposition contributions of SO_2 and sulphates from Sudbury sources were estimated to be both 6%. At Kapuskasing, the impact was greatest with the dry deposition contributions of SO_2 and sulphates from Sudbury sources estimated to be 18% and 7% respectively.

4. Using Tables 7A and 7B, the impact of the Noranda sector (N) on the Dorset site was also assessed. SO_2 dry deposition from sources in this sector on Dorset was estimated to be about 12% in both the Sudbury shut-down period and the analogous period of the previous year. Assuming a background contribution of approximately 3% (similar to that of the Sudbury sector to Dorset) gives a SO_2 dry deposition contribution of about 9% by Noranda sources on the Dorset site. For sulphates, the dry deposition from the Noranda sources were estimated to be about 5%. These percentages appear to be comparable with the contribution of Sudbury sources to Dorset and reflect the larger number of events from the Noranda sector as compared to the Sudbury sector to Dorset during the periods of study.

IV Estimated Relative Air Concentration/Dry Deposition Impact of Sudbury

Method

Surface geostrophic 24 hour forward trajectories (with a frictional correction) were calculated from Sudbury at 1200 GMT every day for the period (6/82 - 3/83), and for similar periods in the 2 previous years. The area around Sudbury was divided into grid squares 38.1 km to a side (1/10 of the CMC grid) and frequencies of trajectory crossings of each grid squares were computed for each of the 3 periods. Contours corresponding to 10, 20 and 40 trajectory crossings were plotted (Figures 3-5).

Results

The first and second periods showed a preference for the trajectories to move eastward (see Figures 3 and 4). The trajectory distribution for the third period, viz. 6/82 - 3/83 (Figure 5) shows a slight preference to the northeast. According to this analysis, this area of potential dry deposition impact extends in every direction from Sudbury, but with a slight preference for the region to the east. This is expected due to the prevailing westerlies.

V. Summary

Meteorological studies to quantify the effects of Sudbury emissions on precipitation quality and air quality during 1980-1983 indicates:

1. Mean sulphate concentrations in precipitation were depressed at central, eastern and southeastern Ontario during the Sudbury emission shut-down period with trajectories from the Sudbury sector. Nitrate concentrations were also depressed.

2. The relative effect on precipitation quality in south and central Ontario due to long range transport from the heavily industrialized North Central U.S. emissions region was probably higher in the shut-down period than it was in the previous analogous periods.

3. Mean sulphur dioxide and sulphate air concentrations were significantly lower at northern, central, eastern and southeastern Ontario during the Sudbury emission shut-down period relative to values for the analogous period from the previous year for Sudbury sector trajectories. For other pollutants, i.e. nitrate, nitric acid and ammonia, the changes in concentrations for the three periods were not statistically significant.

4. Preliminary estimates of the SO_2 dry deposition contribution from Sudbury sources are about 18% to Kapuskasing, 11% to Dorset, 7% to Charleston Lake, 6% to Chalk River and 3% to Longwoods. For sulphates, the approximate dry deposition contributions are 7% to Kapuskasing, 6% to Chalk River and 4% at both Dorset and Charleston Lake.

5. Preliminary estimates of the SO_2 dry deposition contribution from Noranda sources on Dorset are about 9%. For sulphates, the approximate dry deposition contribution is about 5%. These results are comparable to the contribution from Sudbury sources to Dorset and reflect the fact that there were a significantly larger number of events from the north sector than the northwest sector during the three study periods.

6. The area of potential dry deposition impacts extends in every direction from Sudbury, but with a slight preference for the region to the east.

Figure 1

STATION LOCATION MAP

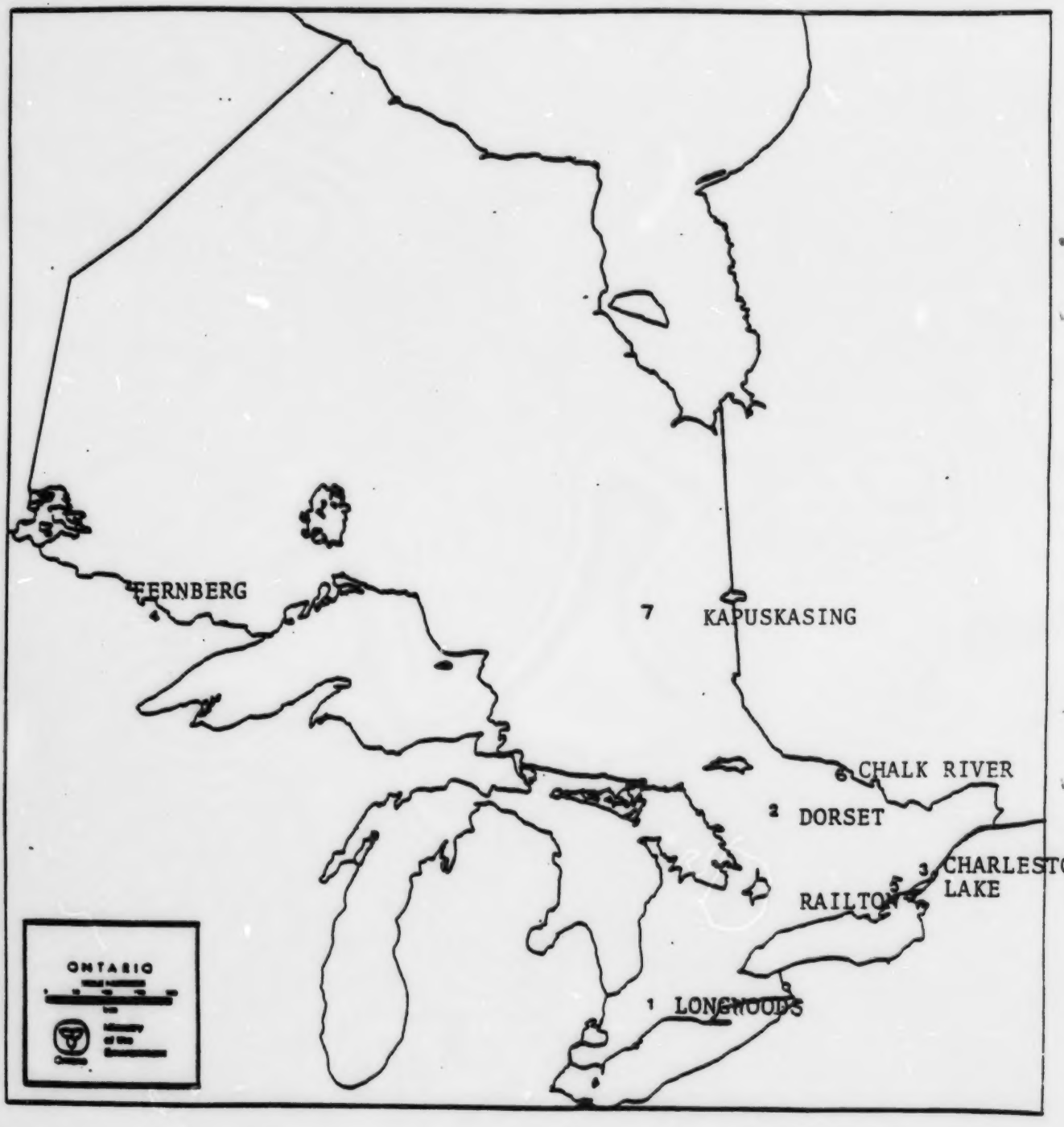
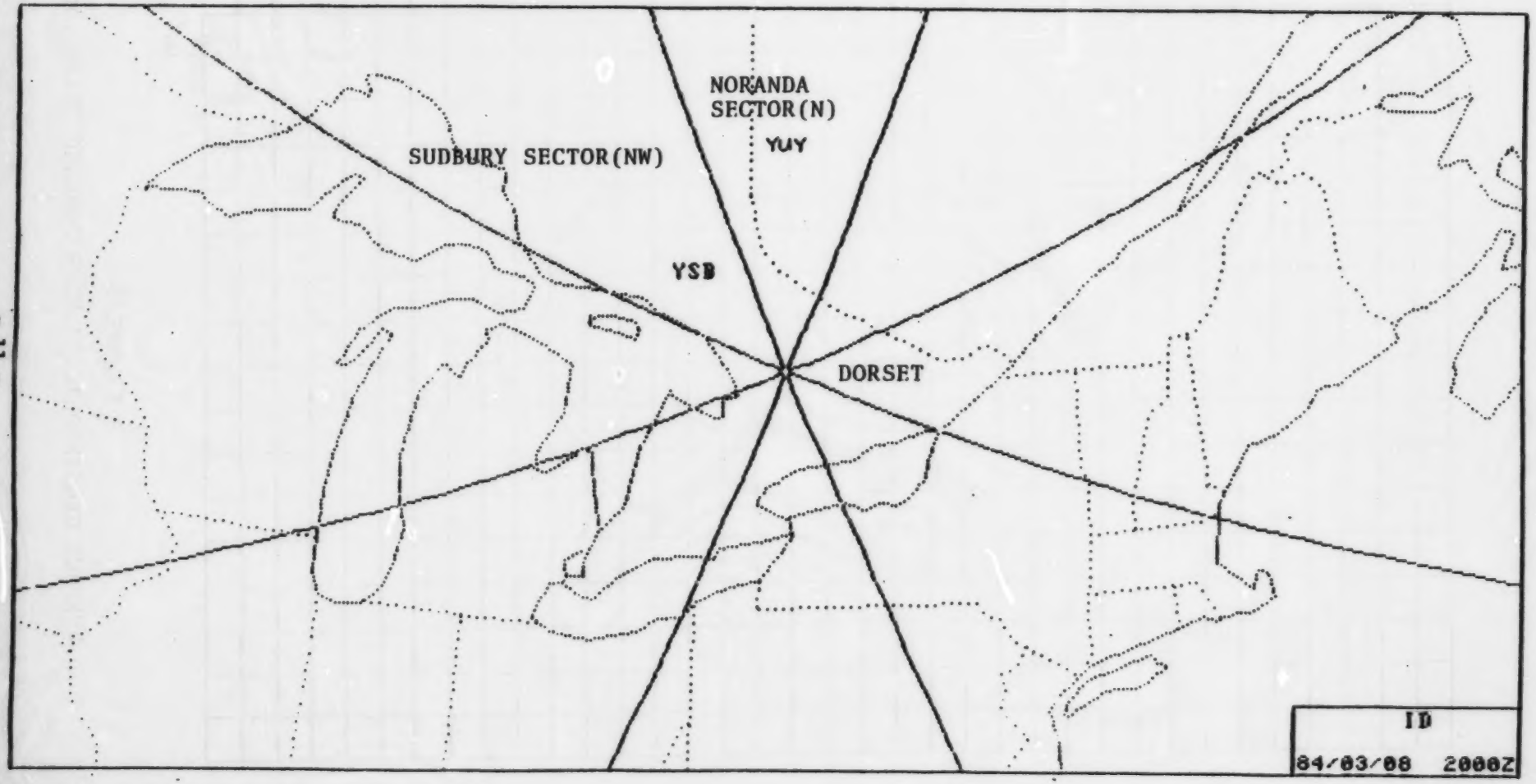


Figure 2. The Sudbury sector(NW) in relation to the Dorset site



PERIOD 3 : 6/82 - 3/83

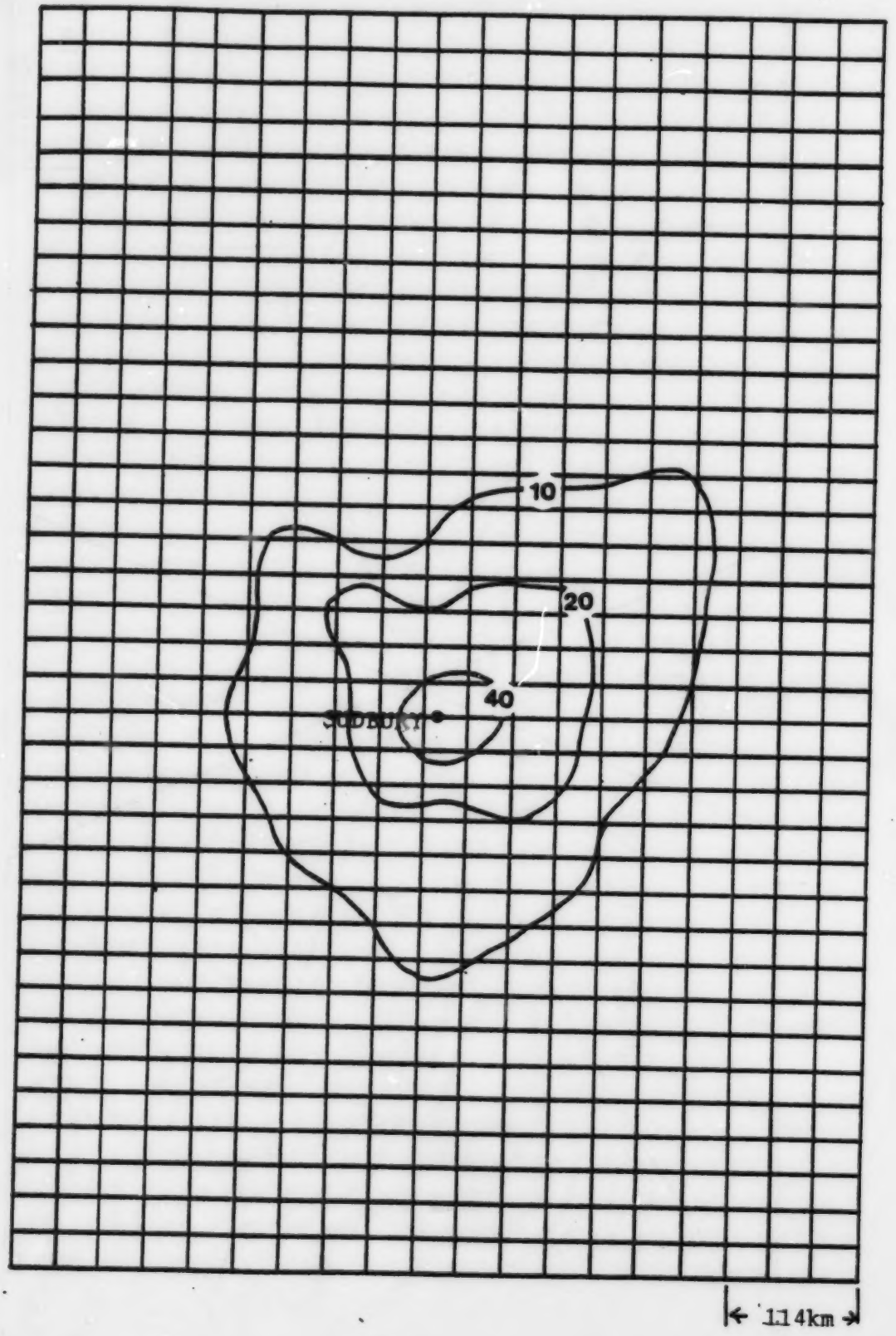


FIGURE 3

SURFACE GEOSTROPHIC 24 HOUR FORWARD TRAJECTORIES FROM SUDBURY

PERIOD 1 : 6/80 - 3/81

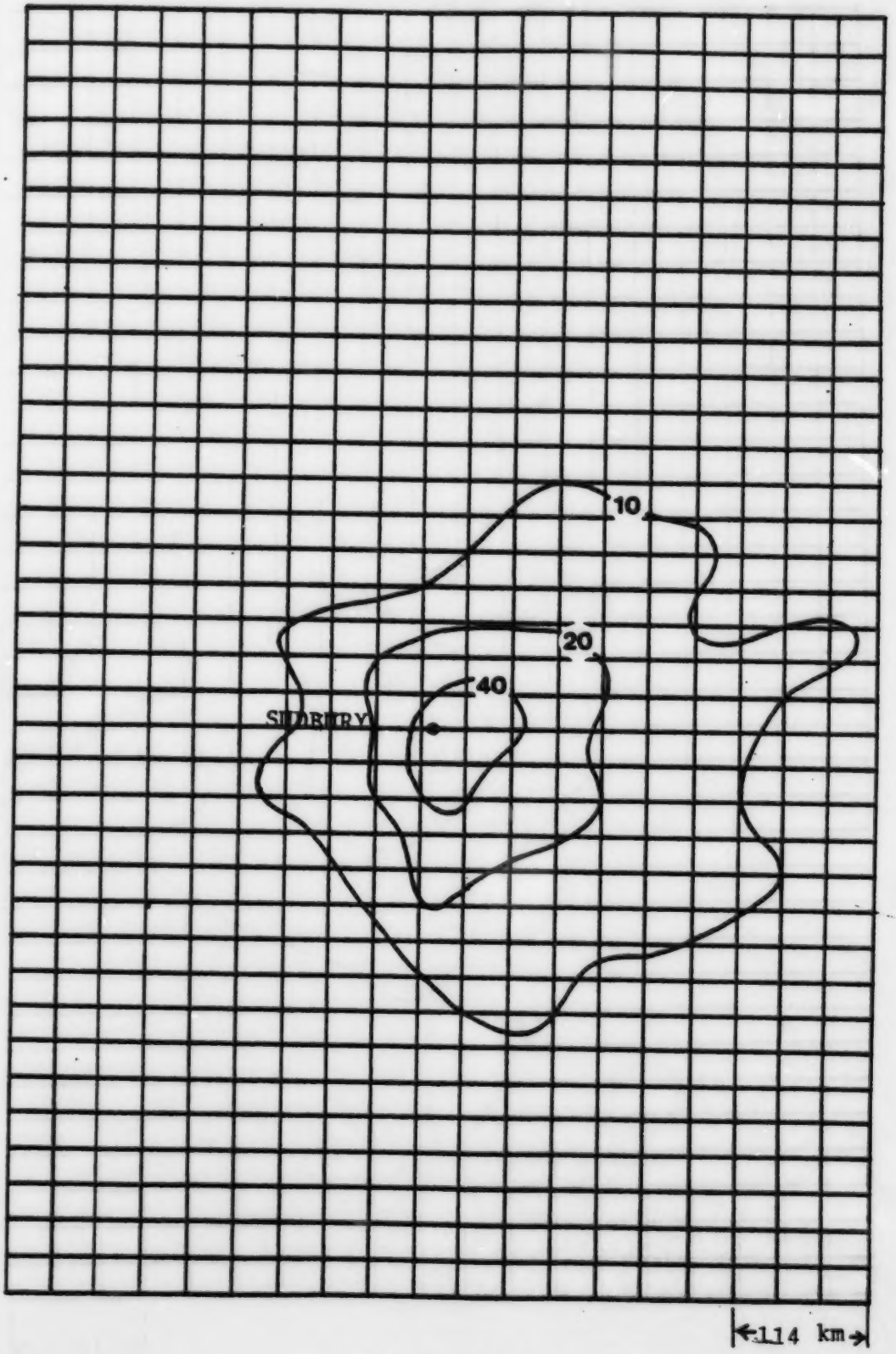


FIGURE 4

SURFACE GEOSTROPHIC 24 HOUR FORWARD TRAJECTORIES FROM SUDBURY

PERIOD 2 : 6/81 - 3/82

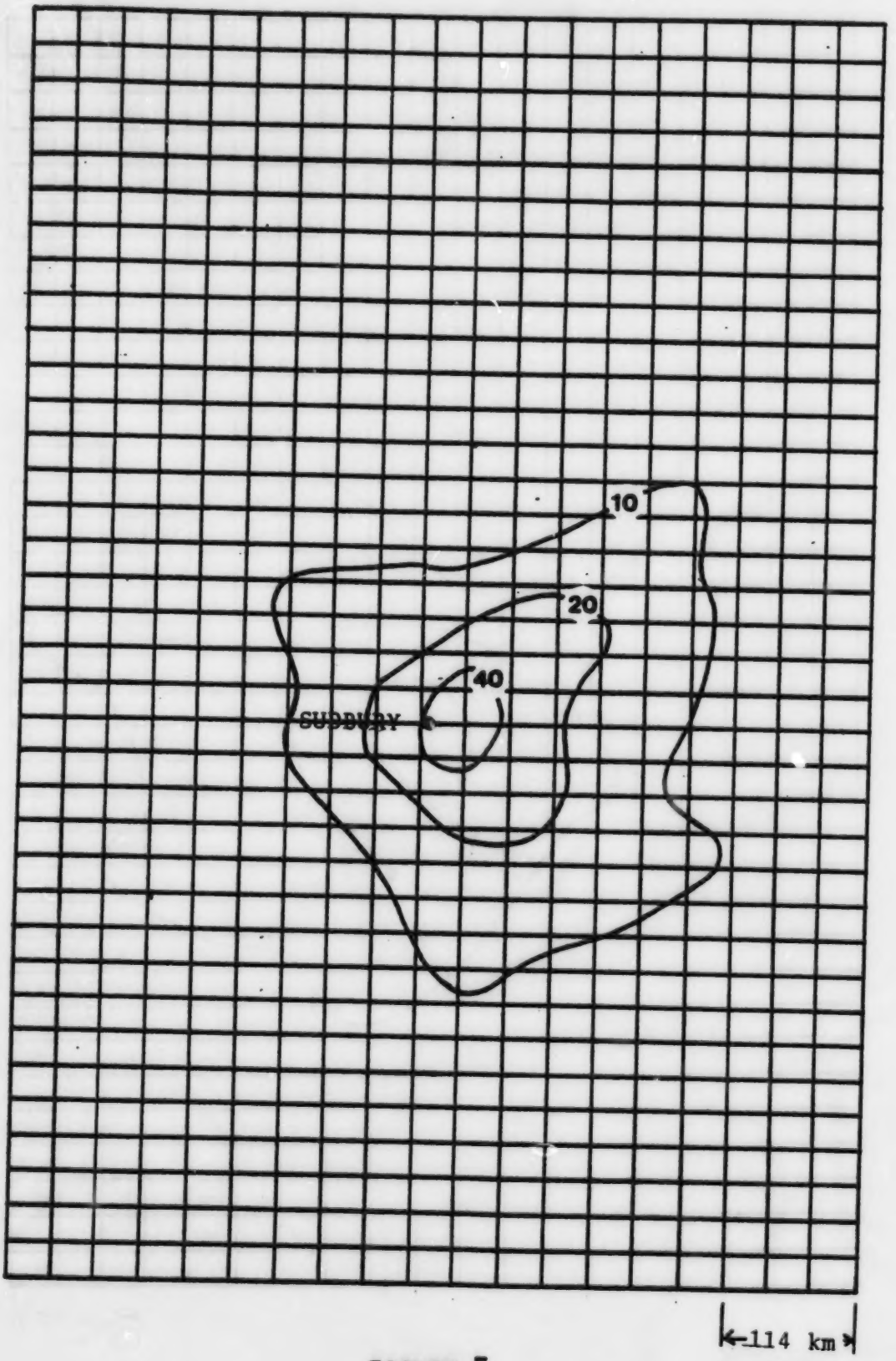


FIGURE 5

SURFACE GEOSTROPHIC 24 HOUR FORWARD TRAJECTORIES FROM SUDBURY

Table 1A

Mean Sulphate Loadings (mg/m^2) (Concentrations (mg/l)) due to the Sudbury Sector

	7/80 - 3/81	7/81 - 3/82	7/82 - 3/83
Dorset	2.2 (1.4)	6.0 (1.4)	3.5 (0.4)
Longwoods	7.8 (3.5)	9.9 (1.5)	5.6 (2.1)
Railton	2.3 (4.2)	7.5 (4.7)	9.2 (1.7)
Fernberg	no data	2.6 (0.8)	11.5 (0.5)
Chalk River	8.6 (3.5)	10.6 (1.8)	6.2 (1.3)
Kapuskasing	no data	no data	7.6 (3.1)

Table 1B

Mean Nitrate Loadings (mg/m^2) and (Concentrations (mg/l)) due to the Sudbury Sector

	7/80 - 3/81	7/81 - 3/82	7/82 - 3/83
Dorset	0.5 (0.4)	0.7 (0.1)	0.5 (0.1)
Longwoods	1.6 (1.0)	2.4 (0.5)	1.6 (0.6)
Railton	0.3 (1.1)	1.4 (0.7)	1.8 (0.3)
Fernberg	no data	0.4 (0.1)	1.1 (0.1)
Chalk River	1.0 (0.4)	3.9 (1.0)	0.6 (0.1)
Kapuskasing	no data	no data	1.1 (0.4)

Table 1C

Total Sudbury Sector Precipitation (mm) and (Number of Events)

	7/80 - 3/81	7/81 - 3/82	7/82 - 3/83
Dorset	8 (6)	30 (4)	18 (8)
Longwoods	37 (14)	25 (10)	21 (9)
Railton	6 (6)	8 (4)	10 (2)
Fernberg	no data	9 (2)	23 (1)
Chalk River	26 (8)	12 (2)	25 (5)
Kapuskasing	no data	no data	24 (7)

Table 2A

Ratios of mean Sulphate Concentration in Precipitation
(Ohio Valley Sector: Sudbury Sector)

	7/80 - 3/81	7/81 - 3/82	7/82 - 3/83
Dorset	1.91	0.99	5.43
Longwoods	1.31	4.46	12.01**
Railton	1.08	1.08	2.48
Fernberg	-	3.76*	2.70**

Table 2B

Ratios of mean Nitrate Concentration in Precipitation
(Ohio Valley Sector: Sudbury Sector)

	7/80 - 3/81	7/81 - 3/82	7/82 - 3/83
Dorset	2.39	1.20	4.01
Longwoods	1.75	1.91	4.73**
Railton	2.31	0.84	2.70
Fernberg	-	13.05*	6.86**

\- no data

* only 1 event in the Ohio Valley Sector. No data for first 3 months of period.

** only 1 event in the Sudbury Sector.

Table 3

Percentage of Events and Percentage of Precipitation Amount for various Synpotic Classes* in 3 Periods at Dorset

Synoptic Class	7/80 - 3/81 Events	7/80 - 3/81 Gauge Depth (mm)	7/81 - 3/82 Events	7/81 - 3/82 Gauge Depth (mm)	7/82 - 3/83 Events	7/82 - 3/83 Gauge Depth (mm)
1	19	5	22	9	19	11
2	11	7	6	2	4	0
3	23	25	32	43	36	46
4	6	4	2	6	6	4
5	22	25	26	35	21	25
6	13	15	4	1	5	3
7	4	17	1	0	2	2
8	3	2	7	4	7	9

* see Appendix for Description of Synoptic Classes

Table 4

Percentage of Events and Percentages of Precipitation Amount for various synoptic Classes* in 3 Periods at Longwoods

Synoptic Class	7/80 - 3/81 Events	7/80 - 3/81 Gauge Depth (mm)	7/81 - 3/82 Events	7/81 - 3/82 Gauge Depth (mm)	7/82 - 3/83 Events	7/82 - 3/83 Gauge Depth (mm)
1	19	13	19	11	15	9
2	8	5	7	13	2	1
3	17	16	25	29	38	40
4	8	11	3	2	4	5
5	19	20	26	24	17	17
6	14	17	7	4	7	4
7	6	13	2	3	5	6
8	8	4	11	15	12	18

Table 5

Percentage of Events and Percentages of Precipitation Amount for various synoptic Classes* in 3 Periods at Railton

Synoptic Class	7/80 - 3/81 Events	7/80 - 3/81 Gauge Depth (mm)	7/81 - 3/82 Events	7/81 - 3/82 Gauge Depth (mm)	7/82 - 3/83 Events	7/82 - 3/83 Gauge Depth (mm)
1	18	9	11	2	11	4
2	0	0	3	2	4	1
3	33	33	32	32	39	48
4	12	22	3	3	5	5
5	21	24	43	54	21	30
6	12	12	4	1	9	3
7	0	0	2	3	2	5
8	4	0	2	3	9	4

Table 6

Percentage of Events and Percentages of Precipitation Amount for various synoptic Classes* in 3 Periods at Fernberg

Synoptic Class	7/80 - 3/81* Events	7/80 - 3/81* Gauge Depth (mm)	7/81 - 3/82** Events	7/81 - 3/82** Gauge Depth (mm)	7/82 - 3/83 Events	7/82 - 3/83 Gauge Depth (mm)
1	-	-	18	11	16	11
2	-	-	4	4	6	3
3	-	-	46	52	40	41
4	-	-	4	1	3	5
5	-	-	14	17	17	21
6	-	-	4	4	4	3
7	-	-	0	0	3	6
8	-	-	11	12	11	10

* no data for this period

** no data for first 3 months of this period

Table 7A

Mean Sulphur Dioxide Air Concentrations (ug/m^3) at Dorset

Sector Analysis - 6h Back Trajectories

Sudbury Sector: NW

Sector	Period 2 7/81 - 3/82 No. of Events	Mean ug/m^3	S.D ug/m^3	Period 3 7/82 - 3/83 No. of Events	Mean ug/m^3	S.D ug/m^3
N	46	3.69	3.97	31	2.74	3.09
NE	19	3.75	4.81	16	2.37	3.52
E	11	2.67	3.95	9	1.44	1.70
SE	25	4.32	7.15	22	4.17	4.22
S	36	10.86	8.75	27	6.33	6.70
SW	28	8.57	8.14	36	7.28	9.25
W	35	4.21	3.86	26	1.76	2.42
NW	23	8.66	12.55	17	1.28	2.41
Unknown	23	4.14	4.94	23	2.64	5.15
Total	246			207		
Average		5.90	7.40		3.81	5.76

Table 7B
Mean Sulphate Air Concentrations (ug/m^3) at Dorset
Sector Analysis - 6 h back Trajectories
Sudbury Sector: NW

Sector	Period 1 7/80 - 3/81			Period 2 7/81 - 3/82			Period 3 7/82 - 3/83		
	No. of Events	Mean ug/m^3	S.D ug/m^3	No. of Events	Mean ug/m^3	S.D ug/m^3	No. of Events	Mean ug/m^3	S.D ug/m^3
N	38	1.53	1.24	50	1.57	2.31	33	1.32	1.17
NE	10	2.72	2.49	19	1.90	2.13	19	1.66	1.77
E	9	2.29	2.08	11	1.46	1.38	11	1.61	0.90
SE	14	2.73	2.37	25	3.27	3.56	23	3.51	3.37
S	23	4.77	3.57	36	6.57	4.82	27	5.75	5.78
SW	39	4.50	2.93	29	6.32	6.28	37	6.38	8.25
W	26	3.39	5.45	36	3.70	4.41	27	2.43	3.01
NW	23	1.42	0.94	22	2.28	1.74	18	0.70	0.72
UNKNOWN	17	2.23	1.56	23	3.15	3.98	23	2.33	3.21
Total	199			251			218		
Average		2.96	3.14		3.54	4.27		3.20	4.82

Table 7C
Mean Nitrate Air Concentrations (ug/m^3) at Dorset
Sector Analysis - 6 h back Trajectories
Sudbury Sector: NW

Sector	Period 1 7/80 - 3/81 No. of Events	Mean ug/m^3	S.D ug/m^3	Period 2 7/81 - 3/82 No. of Events	Mean ug/m^3	S.D ug/m^3	Period 3 7/82 - 3/83 No. of Events	Mean ug/m^3	S.D ug/m^3
N	38	0.04	0.07	48	0.01	0.01	34	0.02	0.01
NE	10	0.06	0.08	18	0.01	0.01	18	0.02	0.01
E	9	0.03	0.04	11	0.01	0.01	11	0.02	0.02
SE	14	0.04	0.06	24	0.03	0.05	23	0.04	0.06
S	23	0.10	0.09	33	0.05	0.08	26	0.10	0.20
SW	38	0.30	0.35	29	0.16	0.17	36	0.15	0.23
W	23	0.27	1.04	34	0.04	0.06	25	0.05	0.13
NW	18	0.01	0.01	19	0.02	0.02	17	0.02	0.02
UNKNOWN	17	0.03	0.03	21	0.03	0.03	22	0.01	0.02
Total	190			237			212		
Average		0.12	0.41		0.04	0.09		0.06	0.14

Table 7D
Mean Nitric Acid Air Concentrations (ug/m^3) at Dorset
Sector Analysis - 6 h back Trajectories
Sudbury Sector: NW

Sector	Period 1 7/80 - 3/81 No. of Events	Period 1 7/80 - 3/81 $Mean_3$ ug/m^3	Period 1 7/80 - 3/81 $S.D_3$ ug/m^3	Period 2 7/81 - 3/82 No. of Events	Period 2 7/81 - 3/82 $Mean_3$ ug/m^3	Period 2 7/81 - 3/82 $S.D_3$ ug/m^3	Period 3 7/82 - 3/83 No. of Events	Period 3 7/82 - 3/83 $Mean_3$ ug/m^3	Period 3 7/82 - 3/83 $S.D_3$ ug/m^3
N	37	0.15	0.33	47	0.12	0.21	34	0.08	0.06
NE	10	0.23	0.20	20	0.15	0.13	19	0.12	0.11
E	8	0.30	0.33	11	0.10	0.08	11	0.11	0.05
SE	14	0.29	0.26	25	0.28	0.22	23	0.40	0.30
S	22	0.61	0.56	35	0.74	0.43	27	0.65	0.49
SW	39	0.68	0.47	29	0.68	0.41	37	0.58	0.43
W	25	0.24	0.22	35	0.35	0.32	25	0.23	0.25
NW	21	0.17	0.17	24	0.14	0.14	17	0.10	0.12
UNKNOWN	17	0.15	0.18	23	0.22	0.15	21	0.31	0.52
Total	193			249			214		
Average		0.35	0.41		0.33	0.36		0.32	0.39

Table 7E
Mean Ammonia Air Concentrations (ug/m^3) at Dorset
Sector Analysis - 6 h back Trajectories
Sudbury Sector: NW

Sector	Period 1 7/80 - 3/81 No. of Events	Mean ug/m^3	S.D ug/m^3	Period 2 7/81 - 3/82 No. of Events	Mean ug/m^3	S.D ug/m^3	Period 3 7/82 - 3/83 No. of Events	Mean ug/m^3	S.D ug/m^3
N	35	0.22	0.24	50	0.28	0.41	32	0.14	0.10
NE	9	0.46	0.38	19	0.28	0.25	17	0.33	0.39
E	9	0.39	0.31	10	0.40	0.30	11	0.35	0.29
SE	14	0.50	0.43	24	0.43	0.28	23	0.66	0.73
S	23	1.05	0.74	33	0.96	0.71	27	1.14	1.15
SW	37	1.30	0.78	30	1.14	0.70	36	1.05	1.17
W	26	0.58	0.89	35	0.72	0.73	27	0.46	0.54
NW	24	0.21	0.18	23	0.42	0.37	18	0.15	0.16
UNKNOWN	13	0.45	0.35	23	0.55	0.53	23	0.42	0.65
Total	190			247			214		
Average		0.63	0.71		0.59	0.61		0.57	0.82

Table 8A
Mean Sulphur Dioxide Air Concentrations (ug/m^3)
Due to the Sudbury Sector

	Period 2 7/81-3/82			Period 3 7/82-3/83		
	No. of Events	Mean ug/m^3	S.D $ug/^3$	No. of Events	Mean ug/m^3	S.D. ug/m^3
Dorset	23	8.66	12.55	17	1.28	2.41
Longwoods	38	4.99	6.34	31	3.00	2.63
Charleston Lake	39	4.67	4.08	19	2.36	3.76
Fernberg	10	2.18	1.50	12	1.17	1.22
Chalk River	23	8.24	10.26	13	1.91	2.55
Kapuskasing	11	7.88	9.19	9	1.75	1.37

Table 8B
Mean Sulphate Air Concentrations (ug/m^3)
Due to the Sudbury Sector

	Period 2 7/81-3/82			Period 3 7/82-3/83		
	No. of Events	Mean ug/m^3	S.D $ug/^3$	No. of Events	Mean ug/m^3	S.D. ug/m^3
Dorset	22	2.28	1.74	18	0.70	0.72
Longwoods	39	2.61	2.22	33	3.03	2.92
Charleston Lake	40	1.52	1.13	19	1.31	0.99
Fernberg	10	0.73	0.70	13	1.09	0.78
Chalk River	23	1.95	1.93	18	0.80	0.62
Kapuskasing	11	4.37	5.64	9	1.90	2.14

Appendix 1

Classification of Synoptic Weather Patterns over Southern Ontario - K.C. Heidorn

In order to study the relationship between synoptic weather patterns and measured pollutants, eight classes have been defined to categorize the daily weather patterns. They are:

Class 1: Post-cold front/pre-high pressure ridge; this class has highest pressure to the west and the gradient flow generally has a northerly component. A cold frontal passage may have occurred on the previous day (Figure 6).

Class 2: High pressure ridge: the area is within the centre or ridge of a high-pressure (anticylonic) system (Figure 7).

Class 3: Post-ridge/pre-warm front: highest pressure is to the east; gradient winds generally have a southerly component. Warm frontal passage may occur on the following day (Figure 8).

The above three classes are associated with the movement of a cell of high pressure. They occur most frequently of all the classes.

Class 4: Warm front: a warm front passing through the area associated with a low pressure system not within the area (Figure 9).

Class 5: Cyclonic: the area contains a cell of low pressure often with associated frontal passages or is influenced by a major cyclonic storm system adjacent to the area (Figure 10).

Class 6: Cold front: a cold front passing through the area associated with a low pressure system not within the area (Figure 11).

Classes 4 through 6 are associated with low pressure systems. Classes 4 and 6 are used only when passage of the front is not associated with nearby cyclonic systems. An example of Class 4 is a warm front sweeping the area from the southwest which extends to a low

moving northeastward across Lake Michigan. An example of Class 6 occurs when a storm system located in the vicinity of James Bay-Hudson Bay has an associated cold front extending across the Great Lakes. Class 4 occurs infrequently.

Class 7: Stationary front: a stationary front lies through the area (Figure 12).

Class 8: Weak pressure gradient: pressure gradient through the region is very weak: direction of flow is due to local influence rather than gradient wind, no clear influence of fronts or pressure systems (Figure 13).

Classes 7 and 8 are weather conditions not tied to a specific wind flow pattern. In Class 7, the study area may be either to the north or the south of the front. It is recognized that the location of the front in relation to the study area may have a profound effect on the distribution of pollutants.

Figure 6

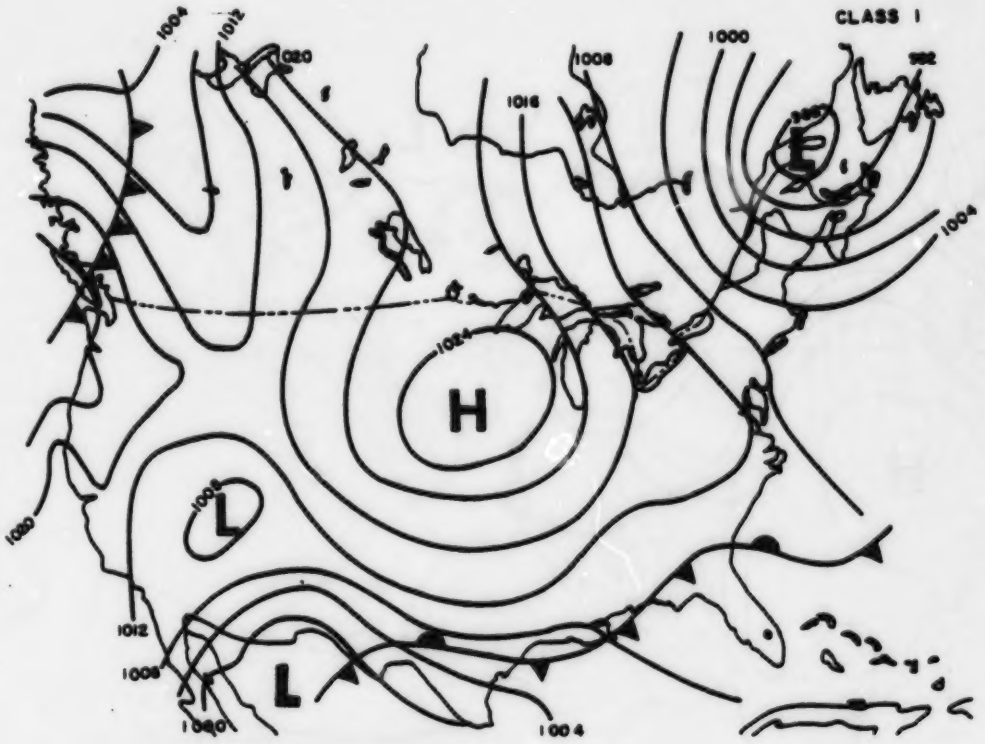


Figure 7

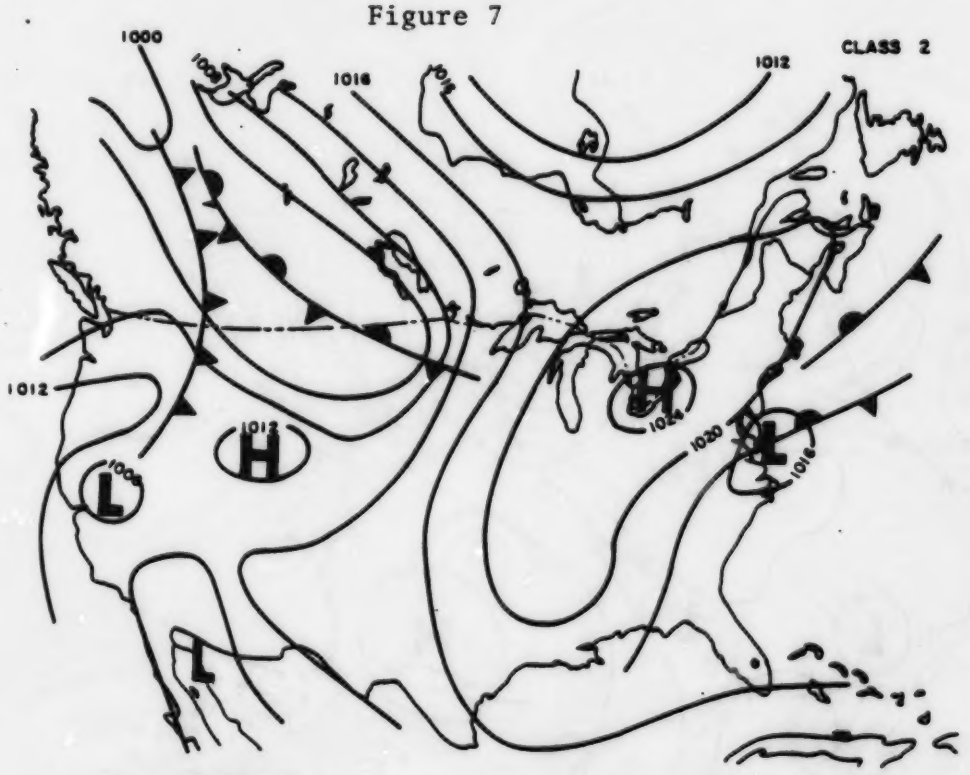


Figure 8

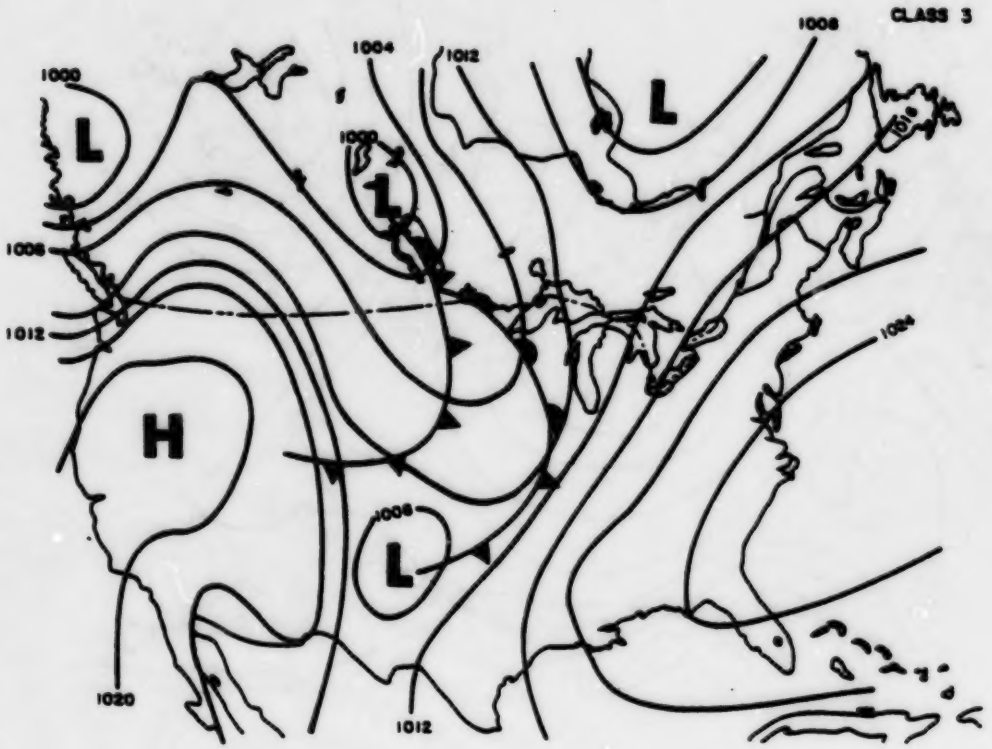


Figure 9

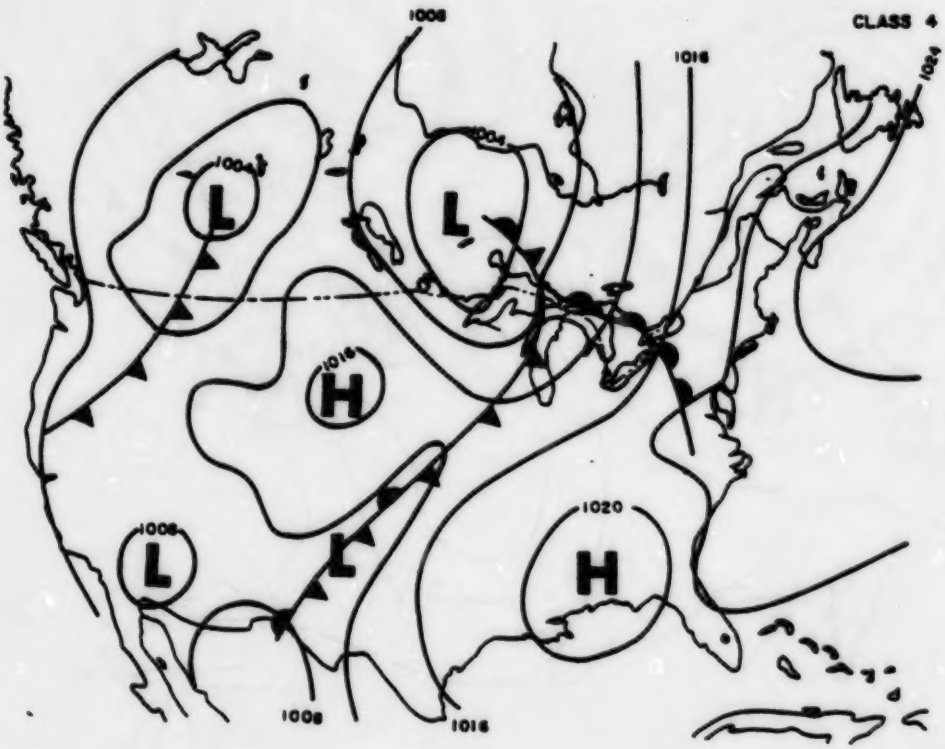


Figure 10

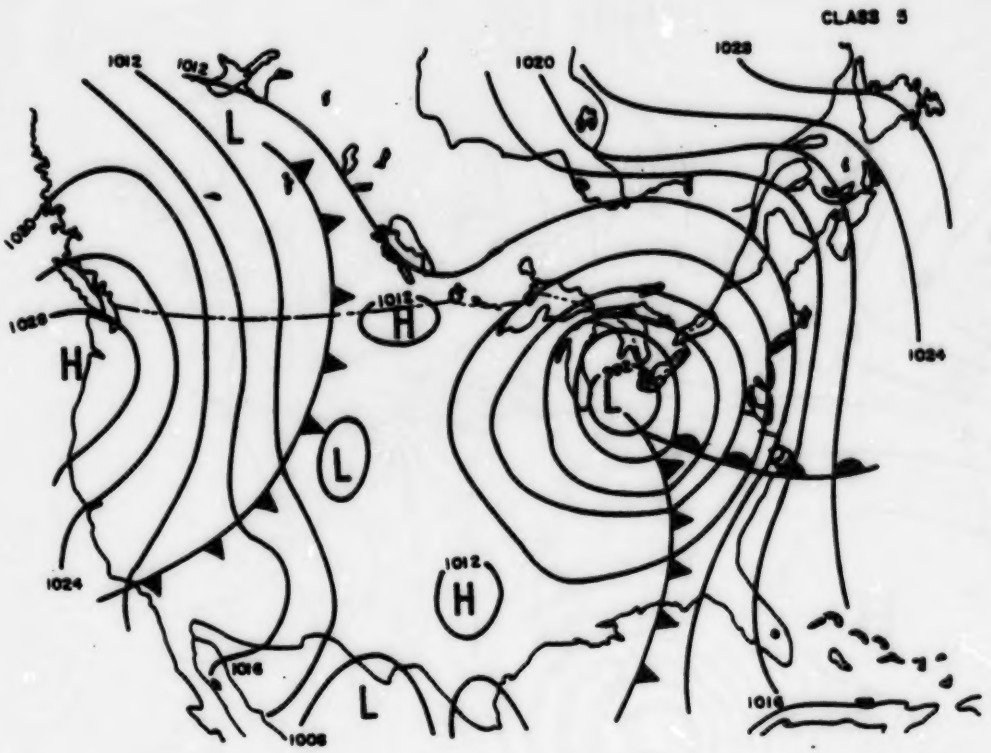


Figure 11

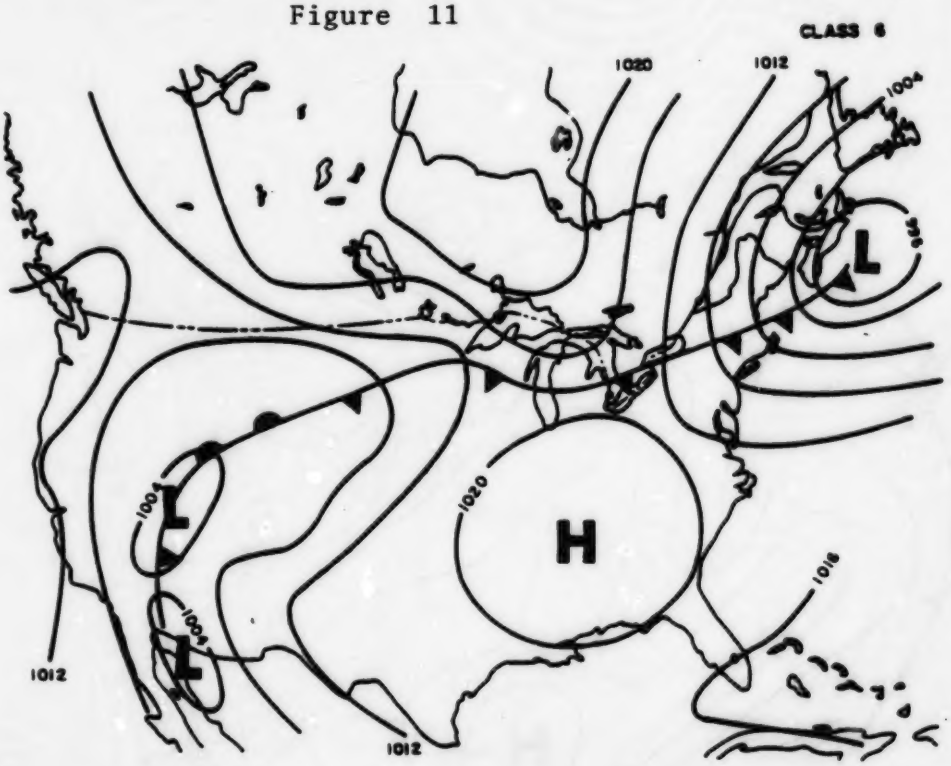


Figure 12

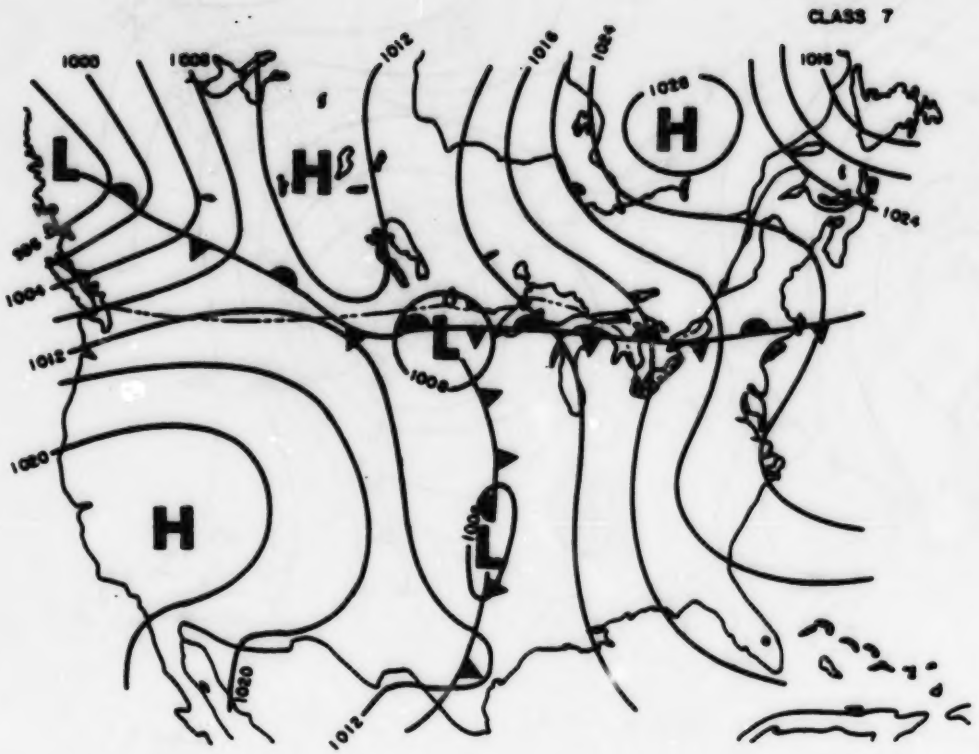


Figure 13